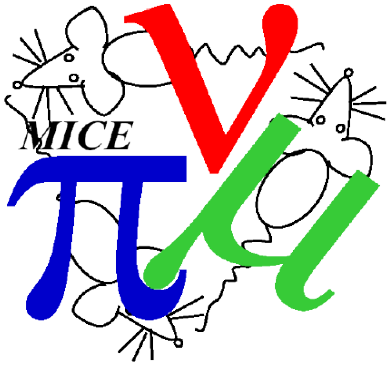
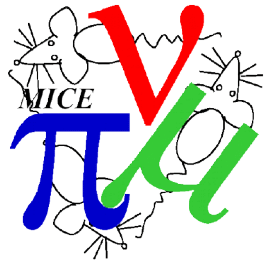
Muon Ionization Cooling Experiment: Results & Prospects



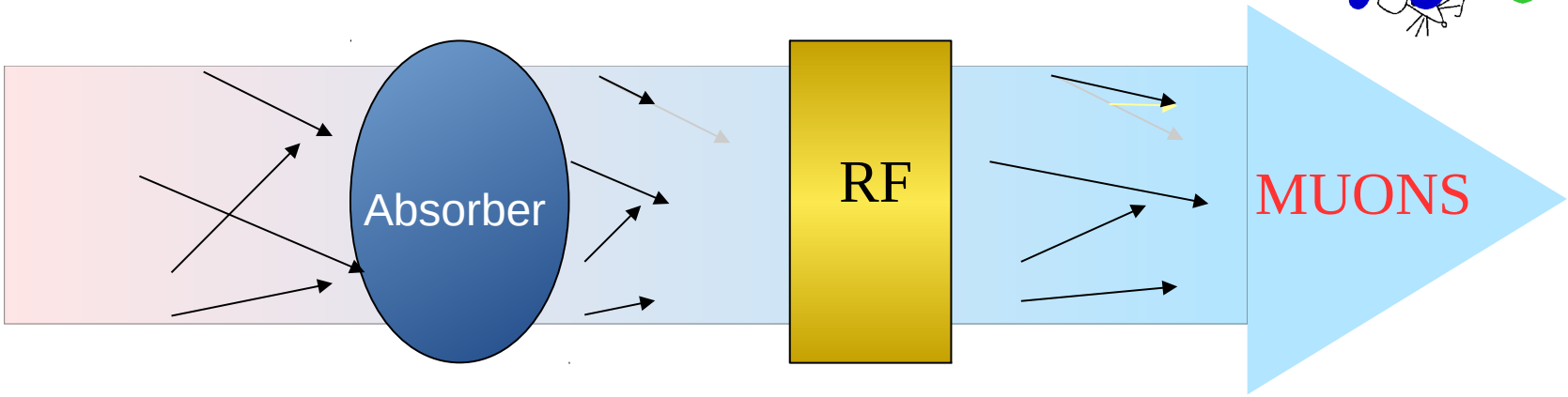
Chris Rogers, ISIS Neutron and Muon Source,
On behalf of the **MICE Collaboration**

Muons at the energy frontier



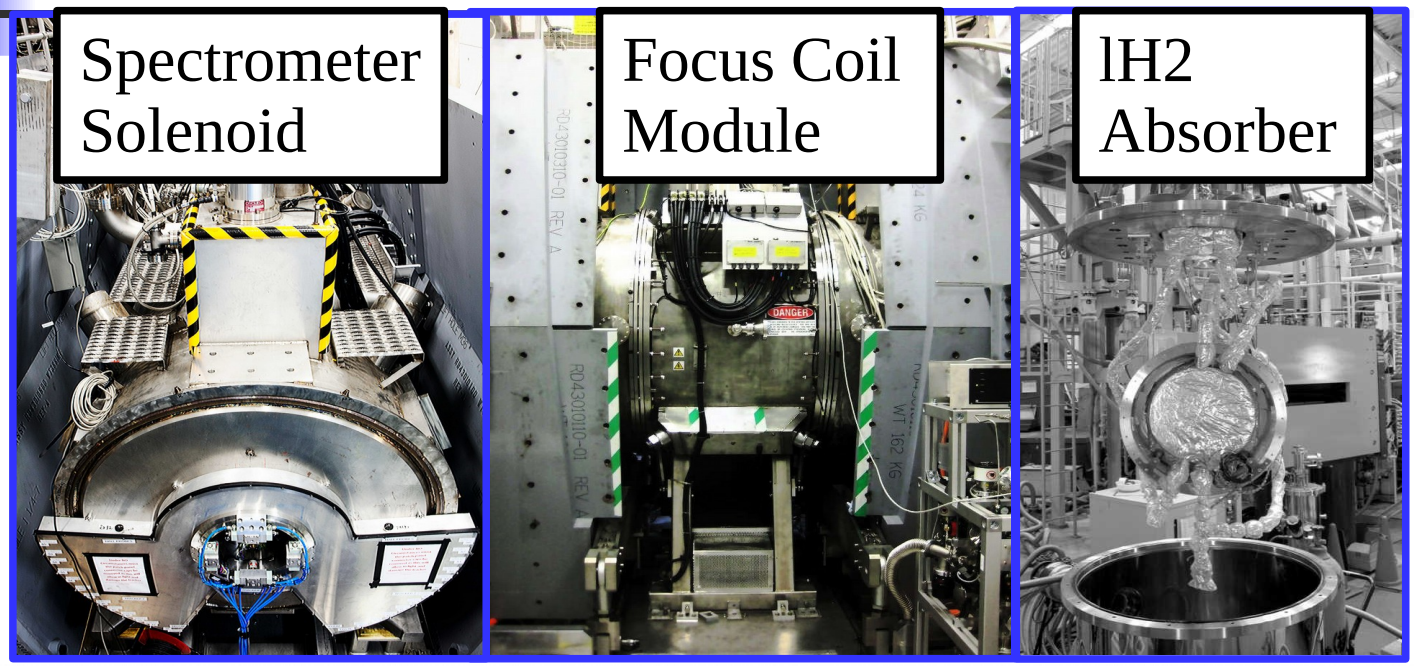
- Growing interest surrounding potential for a muon collider
  - Muon fundamental particle → full energy available for collision
    - Not composite like a proton
  - High mass suppresses synchrotron radiation
  - Recommended as high priority in European Strategy Update
    - New collaboration studying a collider at CERN
    - “Dream machine”
- Muon production challenging
  - Short muon lifetime
  - Produced as tertiary particle → large beam needs cooling
- Need for cooling
  - Traditional techniques not competitive with muon lifetime
  - Ionization cooling – needed to be demonstrated
  - Demonstrated by the Muon Ionization Cooling Experiment

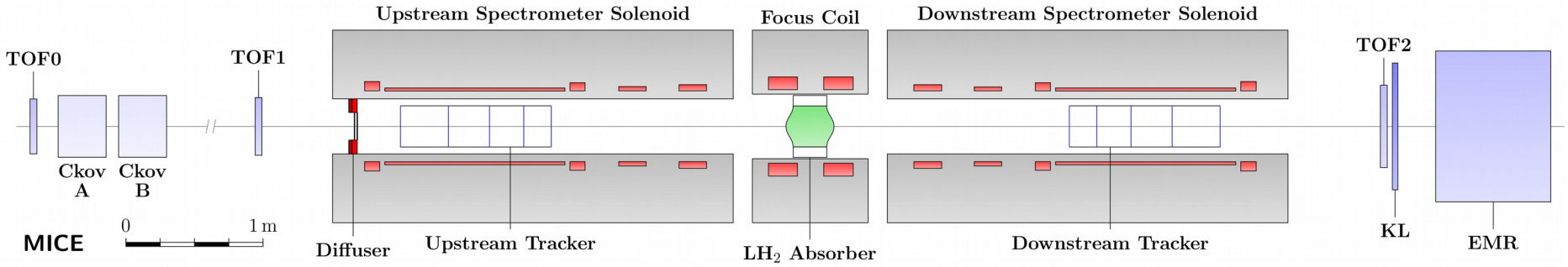
Ionisation Cooling



- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more straight
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing
  - Mitigate with low-Z materials
  - Equilibrium emittance where MCS cancels the cooling

Cooling apparatus

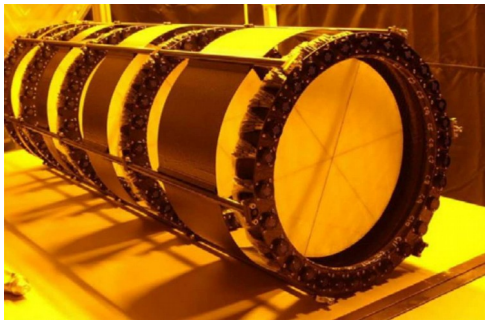


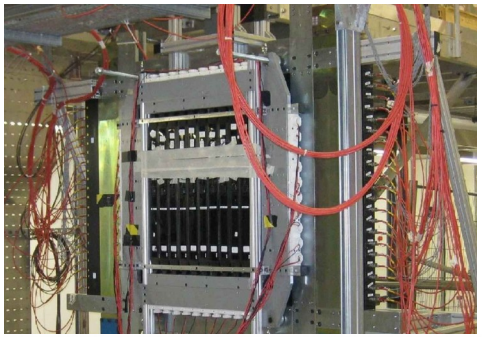


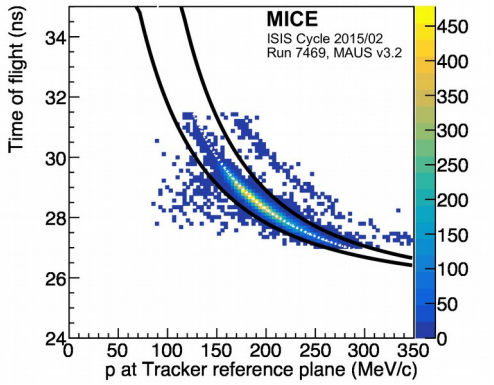
- Spectrometer solenoids upstream and downstream
- Focus coil module provides final focus on absorber
- Choice of liquid Hydrogen, or solid absorbers

Instrumentation

- Scintillating Fibre Trackers
  - Individual muons form a helix in spectrometer solenoids
  - Position of particles measured by 5 stations of scintillating fibres
  - Yields position and momentum of particles
  - Measure “amplitude” of individual muons
    - Distance from beam centre in phase space
- Time-of-flight measurement enables rejection of pion and electron beam impurities
  - Supported by threshold Ckov counters and calorimeters







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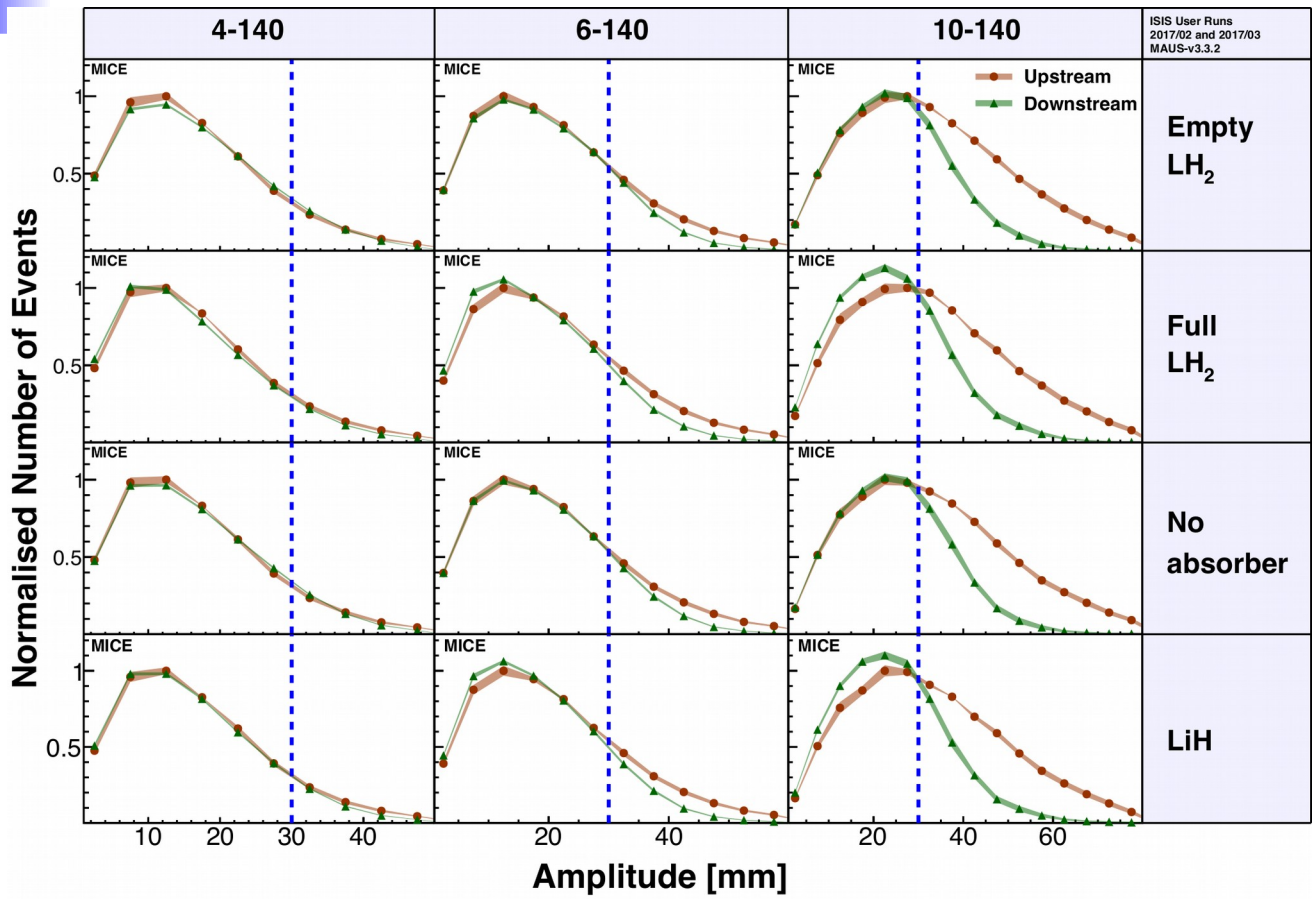
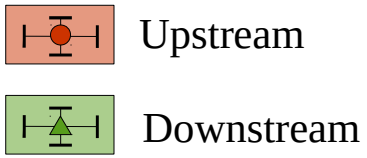
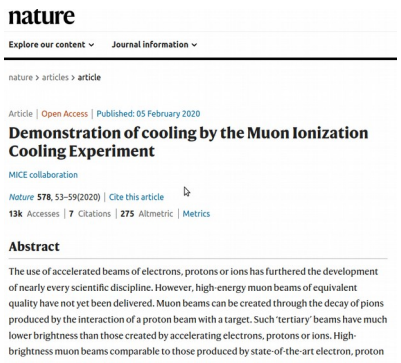
Change in Amplitude Across Absorber



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Article | Open Access | Published: 05 February 2020

Demonstration of cooling by the Muon Ionization Cooling Experiment

MICE collaboration

Nature 578, 53–59(2020) | Cite this article

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Abstract

The use of accelerated beams of electrons, protons or ions has furthered the development of nearly every scientific discipline. However, high-energy muon beams of equivalent quality have not yet been delivered. Muon beams can be created through the decay of pions produced by the interaction of a proton beam with a target. Such 'tertiary' beams have much lower brightness than those created by accelerating electrons, protons or ions. High-brightness muon beams comparable to those produced by state-of-the-art electron, proton

- No absorber → slight decrease in number of core muons
- With absorber → increase in number of core muons
  - Cooling signal

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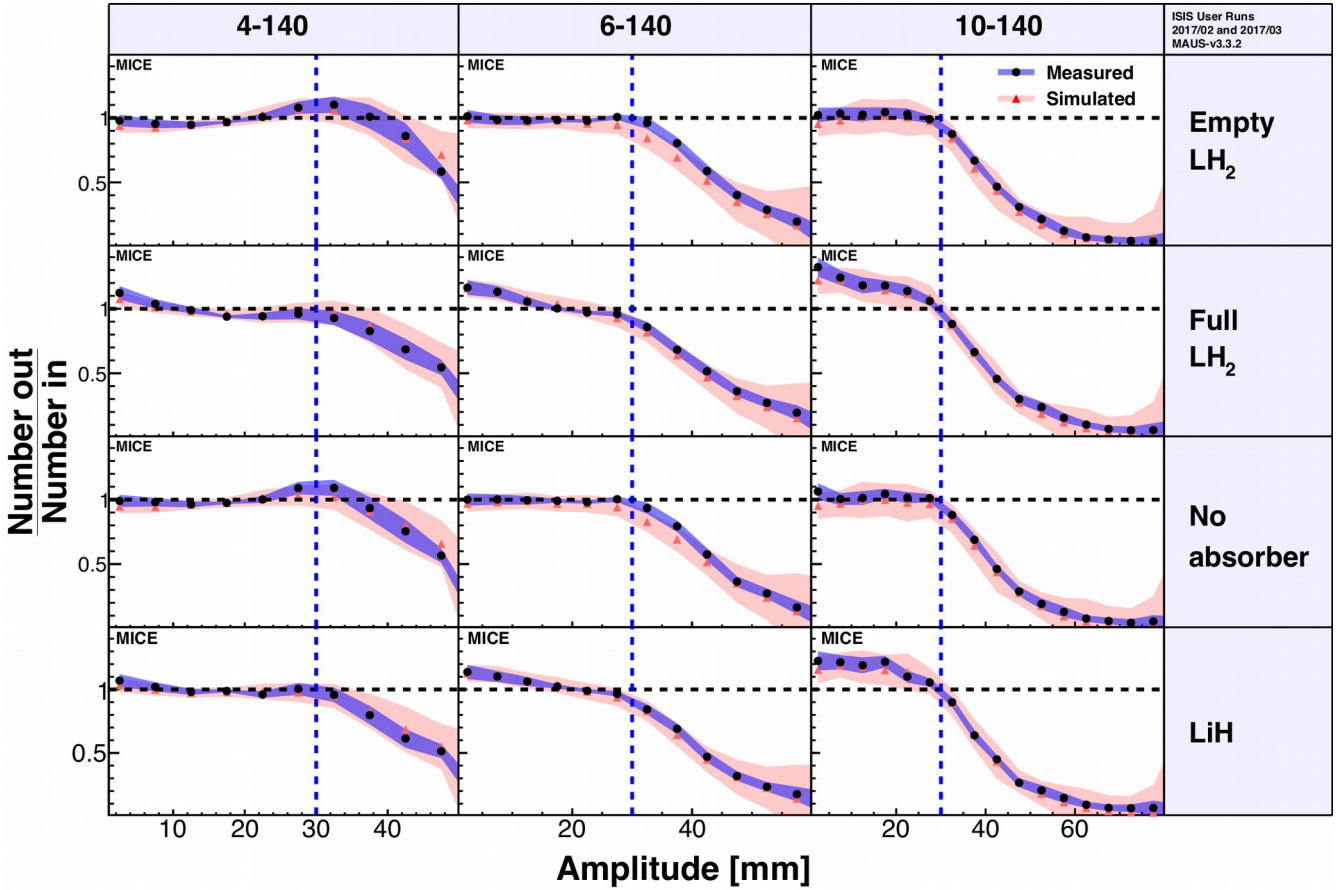
Ratio of core densities



- Core density increase for LH2 and LiH absorber → cooling
- More cooling for higher emittances
- Consistent with simulation

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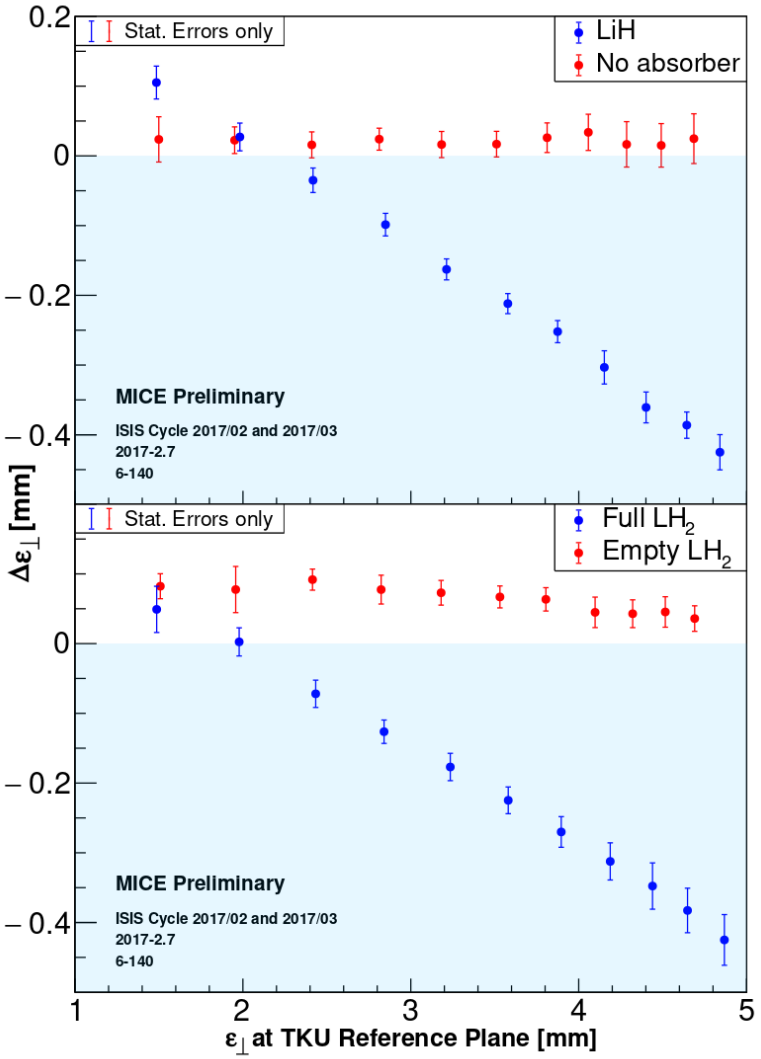
Transverse Emittance

- Also measure change in RMS emittance
  - Mean of the amplitude distribution
- Look at different sub-samples of the muon ensemble
- In absence of absorber weak heating
- With absorber
  - Cooling for high emittance beams
  - Heating below equilibrium emittance
  - Consistent with theory
- Publication in progress



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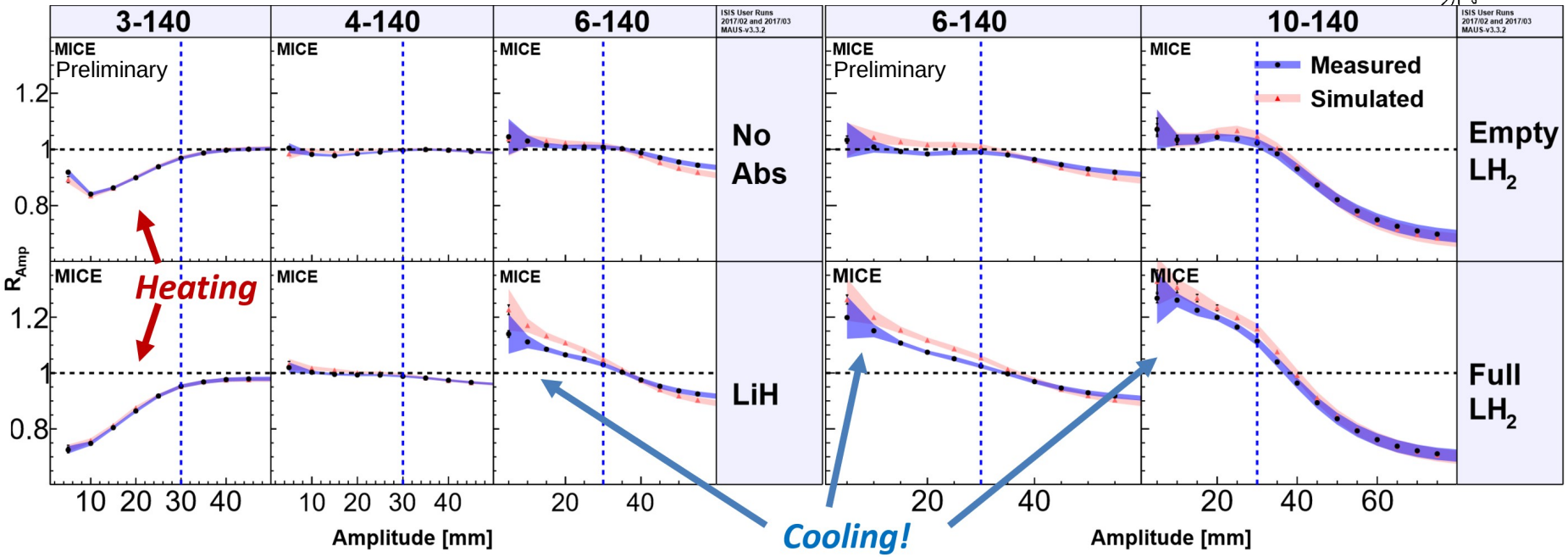
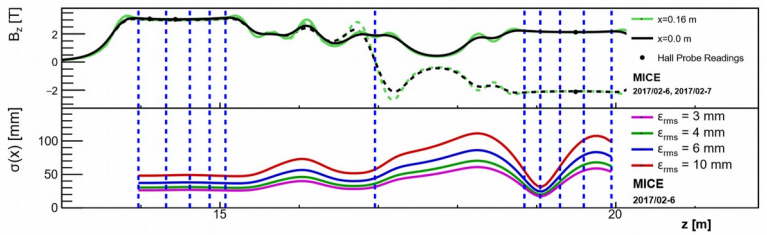
Solenoid Mode



- Most cooling is done at 0 T
- Non-zero T → easier magnets but angular momentum non-conservation
- Studies in progress on cooling performance in solenoid mode



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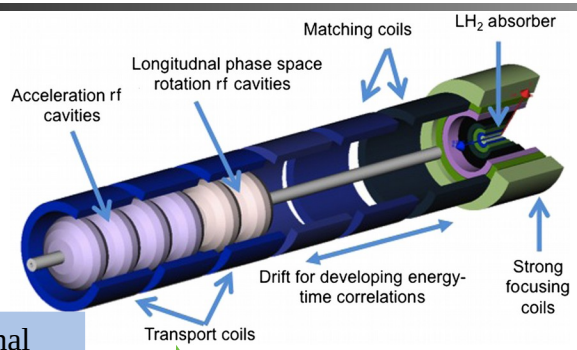
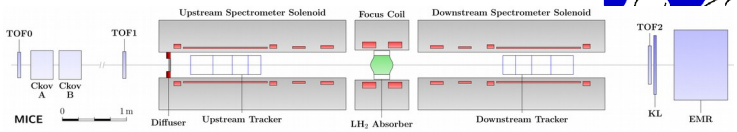
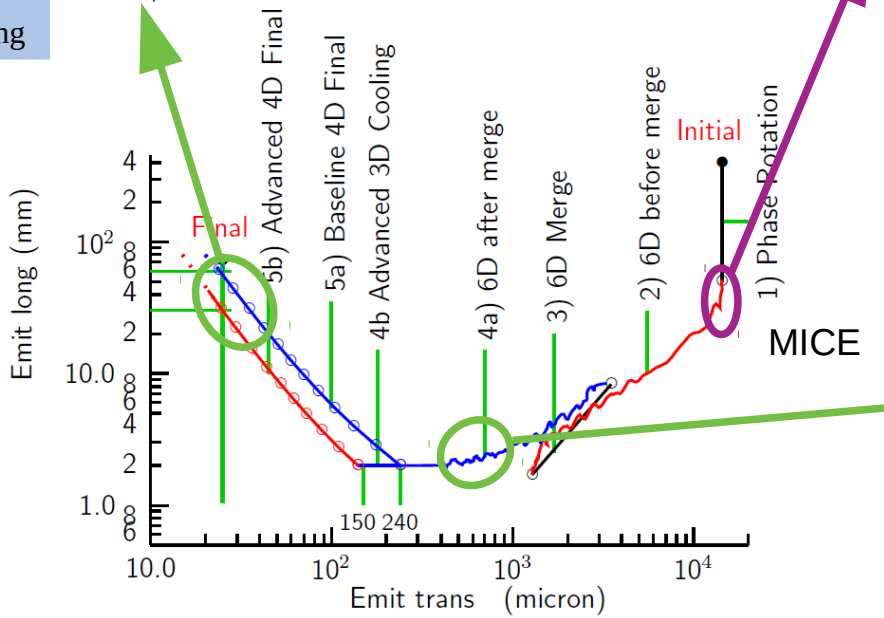
Future Experiment



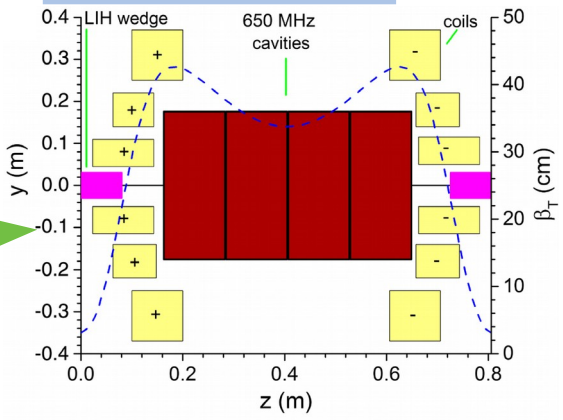
Final cooling



"MICE-like"



Rectilinear B (Stage B8)



- Significant interest in a follow-up experiment
  - Longitudinal and transverse emittance reduction
  - Explore lower emittances

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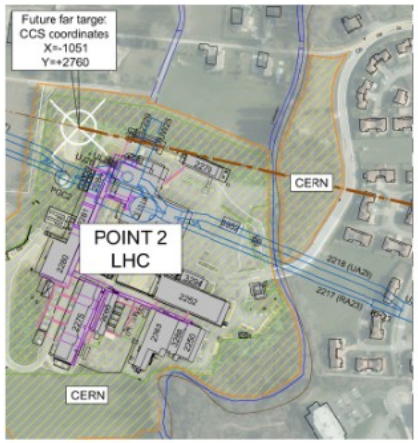
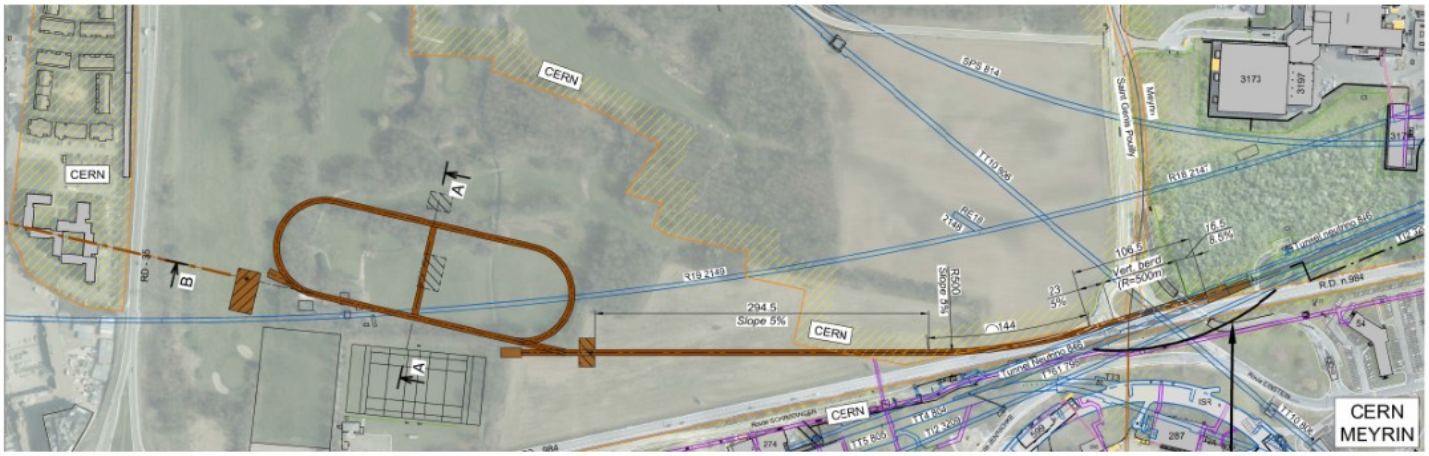
nuSTORM as a Muon Source





- High-brightness muon source needed for a future experiment
- NuSTORM would make an ideal candidate
  - Demonstrate capture and storage of high energy, high current muon beam
- Important physics goals
  - Beyond Standard Model physics including sterile neutrinos
  - Neutrino scattering cross section measurements

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Measurement of Muon Cooling

- Muon collider high priority initiative in European Strategy
  - “Dream machine” for high-energy physics
- High-brightness muon source needed
  - Beam needs to be cooled using ionisation cooling
- MICE built to study muon cooling
  - Unprecedented single particle measurement of particle trajectories in an accelerator lattice
- MICE has made first observation of ionization cooling
- Growing excitement for a follow-up experiment
  - nuSTORM would make an excellent muon source

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